SUSY CONTRIBUTIONS TO R_b AND TOP DECAY

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I report on a systematic analysis of the MSSM parameter space to obtain the best SUSY solution to the R_b anomaly within the constraint of top quark decay. Phenomenological implications for top decay and direct stop production at the Tevatron collider are discussed.

The LEP value of $R_b = .2202 \pm .0016$, obtained by assuming the SM value for R_c; shows a 2.8σ excess over the SM prediction of $R_b = .2157$ [1]. While it is not possible to explain such a large excess via SUSY, we shall consider a SUSY contribution of half this magnitude, i.e.

$$\delta R_b = .0022 \pm .0004, \tag{1}$$

as a viable solution to the R_b anomaly [2]. This will bring the theoretical value of R_b within 1.6σ (90% CL) of the LEP data. Moreover the resulting drop in $\alpha_s(M_Z)$,

$$\delta\alpha_s(M_Z) \simeq -4\delta R_b \simeq -.01, \tag{2}$$

will bring its estimate from $\Gamma_Z^{\rm had}$ in agreement with the DIS value [3]. We shall assume an optimistic upper limit for the SUSY BR of top decay [2],

$$B_s < 0.4, \tag{3}$$

whose validity will be discussed below.

In the low $\tan\beta$ ($\simeq 1$) region of our interest, the SUSY contribution to R_b comes from the lighter stop

$$\tilde{t}_1 = \cos\theta_{\tilde{t}}\tilde{t}_R - \sin\theta_{\tilde{t}}\tilde{t}_L, \tag{4}$$

and the charginos

$$\tilde{W}_{iL} = V_{i1}\tilde{W}_L^{\pm} + V_{i2}\tilde{H}_L^{\pm}\ ,\ \tilde{W}_{iR} = U_{i1}\tilde{W}_R^{\pm} + U_{i2}\tilde{H}_R^{\pm}. \tag{5}$$

The dominant SUSY contributions to $Z \to \bar{b}b$ come from the triangle diagrams involving lighter stop and chargino exchanges, $\tilde{W}_1\tilde{W}_1\tilde{t}_1$ and $\tilde{t}_1\tilde{t}_1\tilde{W}_1$ [4,5]. The b vertices, common to both the diagrams, are dominated by the $b_L\tilde{W}_{1L}\tilde{t}_{1R}$ Yukawa coupling

$$\Lambda_{11}^L \sim -m_t\cos\theta_{\tilde{t}}V_{12}/\sqrt{2}M_W\sin\beta. \tag{6}$$

The Z vertex for the former process is determined by the couplings

$$O_{11}^L \sim \cos 2\theta_W + U_{11}^2\ ,\ O_{11}^R \sim \cos 2\theta_W + V_{11}^2, \tag{7}$$

while it is suppressed for the latter by the U(1) coupling factor $\sim \sin^2\theta_W$. Thus the large b vertex (6) favours large higgsino component of $\tilde{W}_1$ corresponding to the higgsino dominated region ($|\mu| \ll M_2$); but the large Z vertex (7) favours large gaugino components of $\tilde{W}_1$ corresponding to the gaugino dominated region ($|\mu| \gg M_2$) [5]. As we shall see below, the combined requirements of large b and Z vertices give the best value of δR_b for the mixed region ($|\mu| \simeq M_2$) corresponding to a $\tilde{\gamma}$ dominated LSP, rather than the higgsino dominated region favoured by some earlier works [2].

The SUSY BR for top decay ($t \to \tilde{t}_1\tilde{Z}_{1,2}$) is governed by the Yukawa couplings of the lighter neutralinos

$$\tilde{Z}_i = N_{i1}\tilde{B} + N_{i2}\tilde{Z} + N_{i3}\tilde{H}_1 + N_{i4}\tilde{H}_2\ , \tag{8}$$

i.e.

$$C_i^{L(R)} \sim m_t N_{i4}\cos\theta_{\tilde{t}}(\sin\theta_{\tilde{t}})/M_W\sin\beta\ . \tag{9}$$

Thus the higgsino dominated region, corresponding to $\tilde{H}_2$ dominated $\tilde{Z}_1$ and $\tilde{Z}_2$, leads to large values of B_s. One gets relatively small B_s in the mixed region, where only $\tilde{Z}_2$ is higgsino dominated. Thus the top decay constraint (3) favours the mixed region over the higgsino dominated one as well.

Figure 1 shows the SUSY contributions to $R_b(\delta R_b)$ and top BR (B_s) at $\tan\beta = 1.1$ for 3 representative points in the M_2, μ plane [6], *i.e.*

$$M_2, \mu = (a)150, -40\ \ (b)60, -60\ \ (c)40, -70\text{GeV}. \tag{10}$$

The higgsino dominated region (a) is seen to give too small a value of δR_b ($\leq .0014$) for $B_s < 0.4$. On the other hand one gets acceptable solutions to δR_b (1) for $B_s < 0.4$ in the mixed region, represented by the points (b) and (c). The best solutions to δR_b and B_s are obtained for

$$m_{\tilde{t}_1} \simeq 60 \text{ GeV} \quad \text{and} \quad \theta_{\tilde{t}} \simeq -15^\circ, \tag{11}$$

where the stop mass is below the D$\emptyset$ excluded region $m_{\tilde{t}_1} \neq 65 - 88$ GeV [7]. However, the point (c) also gives acceptable values of δR_b for a relatively large stop mass of 90-100 GeV.

Figure 2 shows the contour plots of δR_b and B_s in the M_2, μ plane for $\tan\beta = 1.1$ and 1.4, with the optimal choices of stop mass and mixing (11). The points (a, b, c), shown as bullets, are chosen close to the LEP boundary so as to give the best values of δR_b in their respective regions. The higgsino dominated region, represented by the point a, clearly corresponds to a low δR_b along with an excessively large B_s. One sees a 30-40 % increase in δR_b along with a similar fall in B_s as one goes down to the mixed region, represented by the points b and c. Consequently one gets acceptable values of δR_b (1) for $B_s = 0.3 - 0.4$ in this region. By far the best solution to δR_b and B_s is offered by the point c. But it corresponds to $M_{\tilde{g}} \simeq 160$ GeV, ($M_{\tilde{W}_1} \simeq 80$ GeV), which is just above the Tevatron gluino mass limit of $M_{\tilde{g}} \geq 150$ GeV [8], represented by the x-axis. On the other hand the point b corresponds to $M_{\tilde{g}} \simeq 240$ GeV and $M_{\tilde{W}_1} \simeq 95$ GeV, which are safely above the reaches of Tevatron and LEP-2.

The SUSY BR of

$$B_s = 0.3 - 0.4 \tag{12}$$

has phenomenological implications for the $\bar{t}t$ events at Tevatron [9,10]. The isolated lepton plus n-jet events with b-tag [9] come from the SM decay of one top ($\bar{t} \to \bar{b}\ell\nu$), while the other undergoes SM or SUSY decay

$$t \to bW \to bq\bar{q}', \tag{13}$$

$$t \to \tilde{t}_1 \tilde{Z}_1 \to \tilde{Z}_1 c \tilde{Z}_1 q\bar{q}. \tag{14}$$

The SUSY decay is characterised by a lower detection efficiency (due to the absence of lepton and b and fewer visible jets, but a larger missing-E$_T$ ($\not{E}_T$). They lead to the following differences with respect to the SM prediction [6].

(i) There is a shift of $\sim 10\%$ (i.e.3–4) of the above $\bar{t}t$ events from ≥ 4 jets to the 2 jets channel. Such a shift seems to be favoured by the preliminary CDF data [9], but with large uncertainty.

(ii) The detection efficiency and hence the experimental cross-section in the ≥ 3 jets channel are reduced by a factor

$$(1 - B_s)(1 - B_s/3) = 2/3 - 1/2. \tag{15}$$

This is disfavoured by the CDF cross-section.

$$\sigma_t = 7.5 \pm 1.8 \text{ pb}, m_t = 175.6 \pm 9 \text{ GeV}, \tag{16}$$

which is already larger than $\sigma_t^{\rm QCD}(175) \simeq 5.5$ pb [11]. But the 1.6σ (90% CL) lower limits of σ_t and m_t would correspond to an experimental $\sigma_t (= 4.5 \text{ pb})$ of $\sim 1/2$ the size of the corresponding $\sigma_t^{\rm QCD}(160) \simeq 9$ pb, as required by (14). This is the basis for the B_s limit (3). It will be easier to satisfy with the D$\emptyset$ cross-section, $\sigma_t = 5.3 \pm 1.6$ pb [10].

(iii) There is an 50% enhancement of the large transverse mass ($M_T(\ell \not{E}_T) > 120$ GeV) tail of the above $\bar{t}t$ events. Similarly one expects a $\sim 25\%$ deficit in the $\bar{t}t$ events in the dilepton and double b-tagged channels. Although these are $\leq 1\sigma$ effects for the current Tevatron luminosity of ~ 100 pb^{-1}, they will be 2-3σ effects for the ~ -1 fb^{-1} luminosity expected with the main injector run.

Finally, the large stop mass (90–100 GeV) solution for the point c would correspond to the charged current decay $\tilde{t}_1 \to b\tilde{W}_1$. This would lead to a detectable dilepton signal from stop pair production at Tevatron.

The work reported here was done in collaboration with M. Drees, R.M. Godbole, M. Guchait and S. Raychaudhuri [6].

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Fig. 1. SUSY contributions to R_b (solid) and the top BR (dashed) are shown as contour plots in stop mass and mixing angle for $M_2, \mu =$ $(a)150, -40 (b) 60, -60, (c) 40, -70$ GeV with $\tan(\beta) = 1.1$.

Fig. 2. SUSY contributions to R_b (dashed) and top BR (dotted) shown as contour plots in the M_2, μ plane for stop mass (mixing angle) of 60 GeV (-15°), with $\tan\beta = (a)$ 1.1, (b) 1.4. The boundary of the region $m_{\tilde{t}_1} < M_{\tilde{Z}_1}$ is not shown in (b).

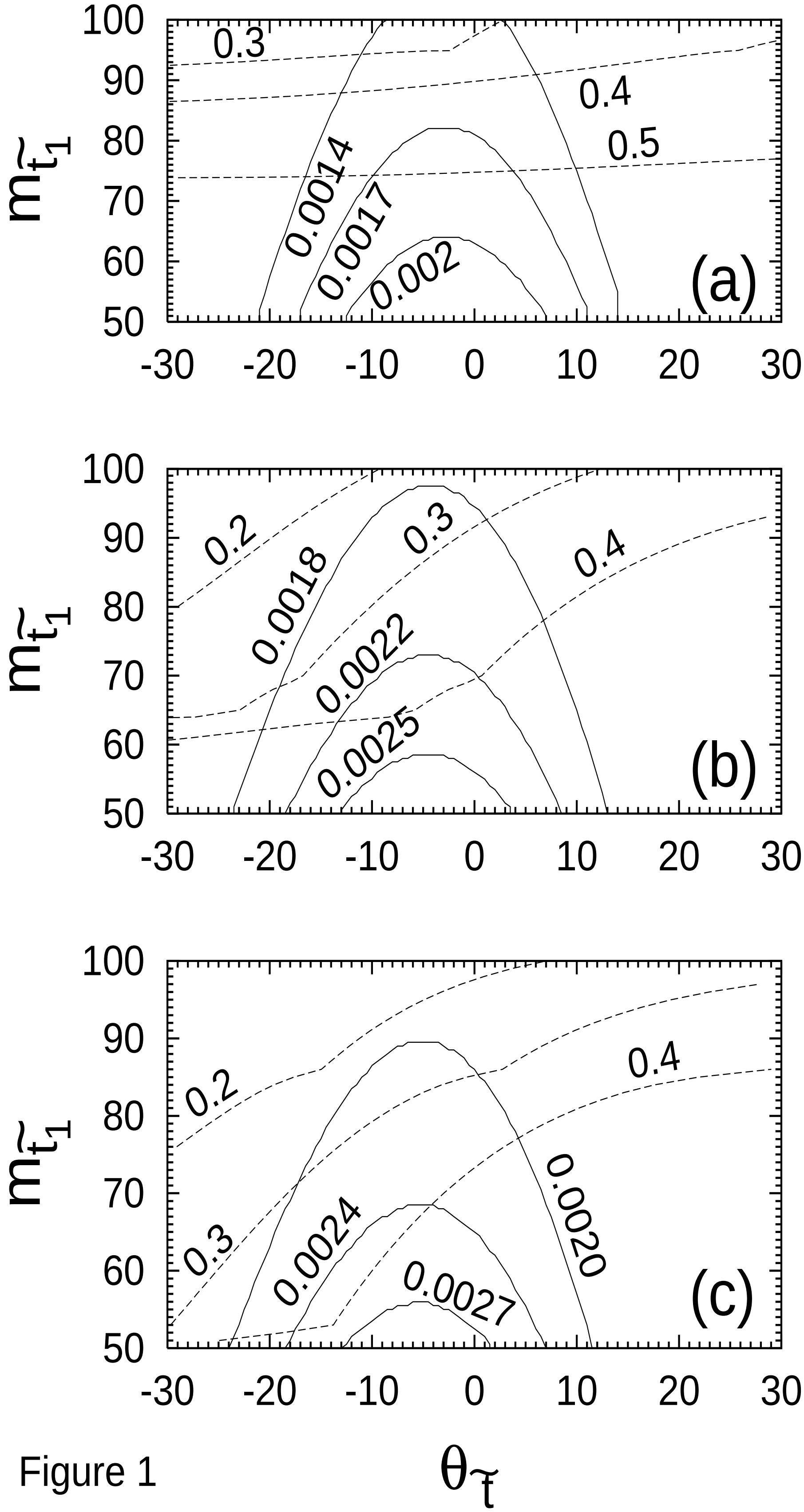
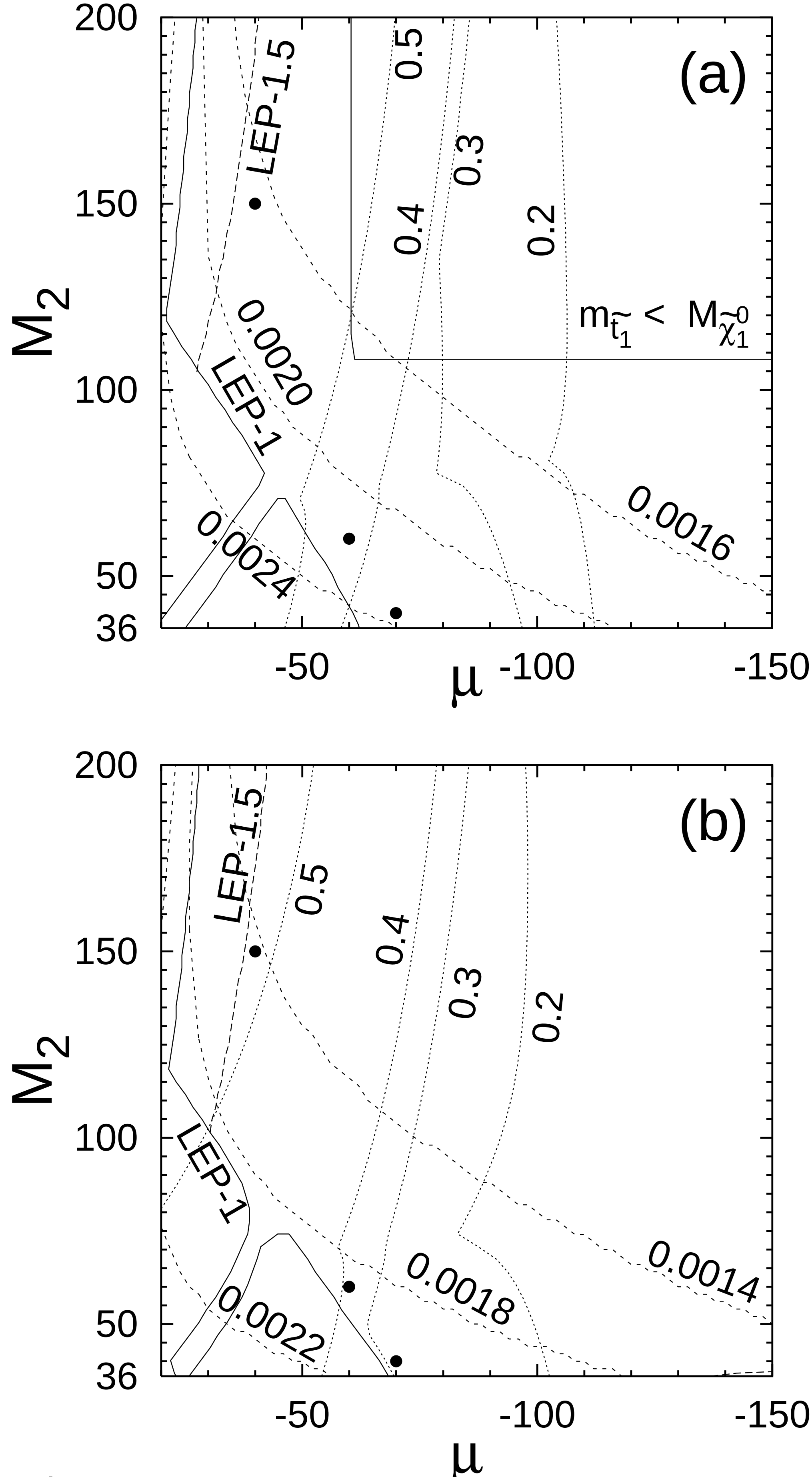

(a)
0.3
0.4
0.5
0.0014
0.0017
0.002
(b)
0.2
0.3
0.4
0.0018
0.0022
0.0025
(c)
0.2
0.3
0.4
0.0020
0.0024
0.0027
100
90
80
70
60
50
-30
-20
-10
0
10
20
30
$m_{\tilde{t}_1}$
$\theta_{\tilde{t}}$

Figure 1



(a)
200
150
100
50
36
-50
-100
-150
M_2
μ
LEP-1.5
LEP-1
0.5
0.4
0.3
0.2
0.0020
0.0024
0.0016
$m_{\tilde{t}_1} < M_{\tilde{\chi}_1^0}$
(b)
200
150
100
50
36
-50
-100
-150
M_2
μ
LEP-1.5
LEP-1
0.5
0.4
0.3
0.2
0.0022
0.0018
0.0014

Figure 2